

Spacecraft Doppler Tracking with the Deep Space Network in the Search for Gravitational Waves

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The Deep Space Network is a telecommunications facility managed by the Jet Propulsion Laboratory, California Institute of Technology, for the National Aeronautics and Space Administration. Its primary function is to provide communication between the Earth and the spacecraft exploring our solar system. It consists of three complexes situated at approximately equally spaced longitudinal intervals around the globe in California and Spain in the northern hemisphere, and Australia, in the southern hemisphere. Its antennas, ranging in diameter from 26 meters to 70 meters, are instrumented with high-power transmitters, low-noise amplifiers and receivers, and appropriate monitoring and control capabilities. In addition to its primary function, the Network generates accurate radio science data observable for investigators who use radio links between spacecraft and the Earth to examine small changes in the phase and/or amplitude of the signal to study structure of the atmospheres, ionospheres, and rings of the planets, planetary gravitational fields, shapes and masses, phenomena in the solar corona and comet material, and aspects of the theory of general relativity such as gravitational redshift and gravitational waves. A gravitational wave is a propagating, polarized gravitational field, a ripple in the curvature of space-time. In Einstein's theory of general relativity, the waves are propagating solutions of the Einstein field equations. Their amplitudes are dimensionless strain amplitudes that change the fractional difference in distance between test masses and the rates at which separated clocks keep time. Predicted by all relativistic theories of gravity, they are extremely weak (the ratio of gravitational forces to electrical forces is about 10^{-40}) and are generated at detectable levels only by astrophysical sources - very massive sources under violent dynamical conditions. The waves have never been directly detected but searches in the low-frequency band using Doppler tracking of many spacecraft have been conducted and others are being planned. Upper limits have been placed on the gravitational wave strength with the best sensitivities to date are for periodic waves being 7×10^{-15} (1σ) (Anderson et al., 1992). Recent observations used the Galileo, Ulysses, and Mars Observer spacecraft (Stabrook, 1988; Bertotti et al., 1992) in a coincidence experiment in 1993. Expected sensitivity for periodic waves in that experiment is 10^{-15} . Before 2000, the Cassini spacecraft, with a Ka-band radio link, ultrastable instrumentation, and the ability to remove phase scintillations due to the wet troposphere, will be used for much higher sensitivity observations, 10^{-16} for periodic waves for one month of tracking near solar opposition.

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